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Modelling the flow of aqueous humor in anterior chamber of the eye

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Abstract

A simple mathematical model for the natural convectional flow of aqueous humor in the anterior chamber of a human eye is developed. The model treats the flow as viscosity dominated due to its low Reynolds number and driven by buoyancy affects because of the temperature gradient (though small but significant) across the anterior chamber. The model incorporates Beavers and Joseph slip flow condition and the convection boundary condition at porous posterior surface of the cornea. The expressions for the temperature and velocity profiles in the anterior chamber as well as for the stream function are obtained. The computational results are presented through graphs and the effects of model parameters: the convection heat transfer coefficient, the thermal conductivity and the slip parameter on the velocity and temperature distributions also have been shown and discussed.

Keywords: Anterior chamber; Aqueous humor; Natural convection; Convection heat transfer coefficient; Thermal conductivity

1. Introduction

The eye is a fantastically complex organ controlled by mechanical, biological, chemical and neurological factors which, under physiological conditions, assure the stability and regulation of the intraocular pressure. This stability and regulation is essential for the visual function of the eye. The fluid dynamics within the eye have an important role in governing the eye's visual functions. The disturbance in fluid dynamics of the eye contributes to the development of several pathological states. Despite numerous studies conducted to examine the involvement of fluid flow phenomenon in normal functions of ocular components as well as in the development of several pathological states in the eye, many aspects of fluid dynamics of the eye have not been fully explained.

The anterior segment of eye is filled with a transparent fluid, aqueous humor and the posterior segment (vitreous body) is occupied by a fluid, vitreous humor (Fig. 1). Anterior segment of the eye is comprised of two chambers, the anterior chamber (between the iris and the cornea) and posterior chamber (the region behind the iris and the anterior to the lens/hyaloid membrane). The intraocular fluid aqueous humor is

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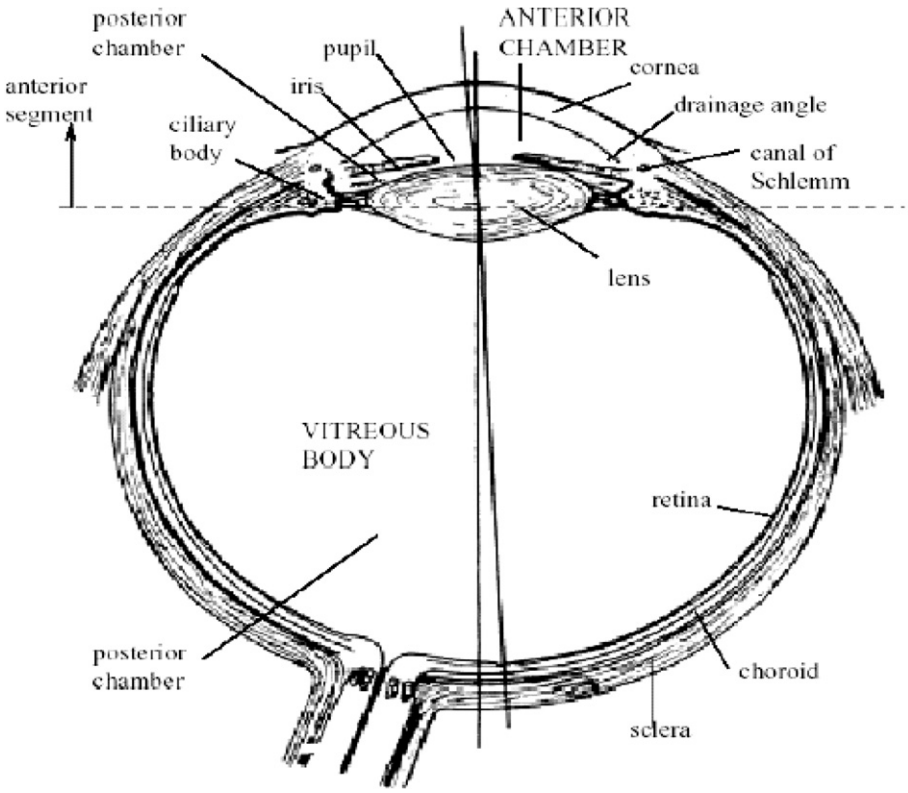

Fig. 1. The eye.

secreted continuously by the ciliary epithelium in to the posterior chamber of the eye. It flows through the pupil aperture in the centre of the back wall of the anterior chamber, in order to reach anterior chamber.

Aqueous humor occupying the anterior chamber provides a transparent medium for its optical function and regulates the intraocular pressure. Besides, it forms part of the pathway for topically applied drugs and for nutritional supply to and metabolites removal from avascular cornea. In both situations, solutes travel at least several millimeters, a distance for which diffusion is slow [5]. Wyatt [5] suggested that the speed of this pathway is greatly enhanced by aqueous humor conventional flow. Conventional flow of aqueous humor in the anterior chamber was first observed by Ehrlich [3] and explained by Turk [7,8]. The basis for this flow is a temperature difference across the chamber, with a cooler anterior surface (the cornea) and a warmer posterior surface (the iris). Thus, the conventional flow in the anterior chamber is caused by thermal processes.

Such flow may be relevant to various aspects of eye diseases. It may assume greater importance in cases where particulate matter is present in the anterior chamber. In cases of severe eye trauma or a as a result of certain diseases and medical conditions particulate matter may be introduced into the anterior chamber. Canning et al. [2] developed a model for fluid flow in the anterior chamber of human eye and analyzed the motion and distribution of such particles. It was concluded that their model was capable of predicting well established and observed features that may be present in a traumatized eye such as hyphemas, keratic precipitates, hypopyons and Krukenberg's spindles.

Aqueous humor in the contact of iris surface at the back of the anterior chamber is warmer (close to core body temperature 37 °C) than that in the contact of posterior cornea surface, which forms the front wall of the chamber. Warmer aqueous humor (the less dense) fluid tends to rise (opposing gravity) near to the back of the chamber through the surrounding cooler fluid and tends to fall towards the front. The cooler (the more dense) fluid that flows into replace the rising warmer fluid will warm up and also rise. The result is circulation (i.e. convection current –"natural" or "free" convection). Thus, the temperature difference between the cornea and the iris, causes circulation of aqueous humor in the anterior chamber of the eye. This convection current is due solely to the non-uniformity of aqueous humor temperature. Being slow moving fluid, this fluid movement is